Issues in Shuttle System Instrumentation

George James

NASA-JSC/SED/ES2

*Technical Manager - **Space Shuttle Loads & Dynamics Panel***
*Structures & **Dynamics Branch - NASA-JSC***

And

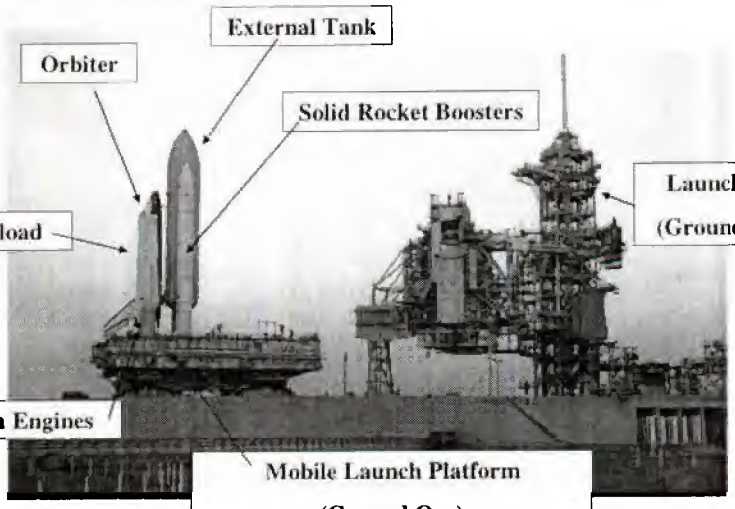
2004 Structural Engineering Division Representative to the
NASA-JSC MEMS & Nanotechnology Initative

11/2/04

Purpose

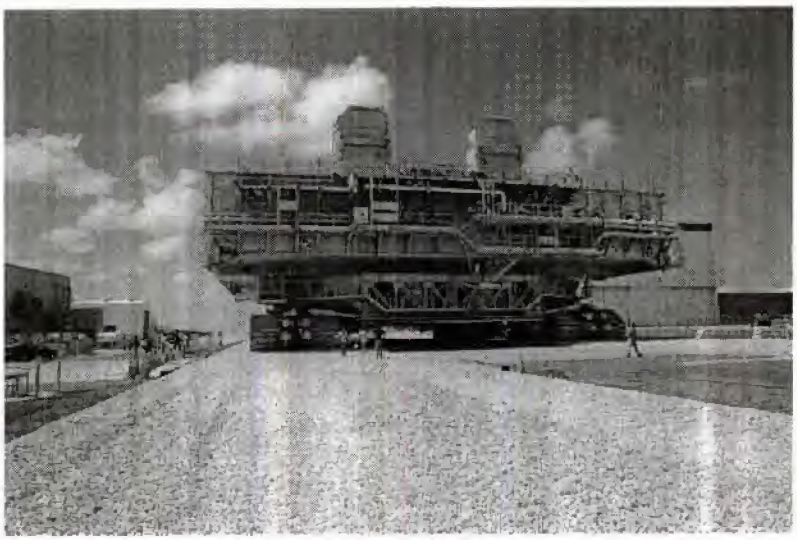
1. **Customer's perspective on Space Shuttle Return-To-Flight (RTF) Instrumentation.**
2. **Focus on the difficult instrumentation issues.**
3. **Enable a discussion of new technologies (I.e. – NANO/MEMS/Small Tech) that could enhance Shuttle instrumentation posture.**

Shuttle System Overview - Hardware



3

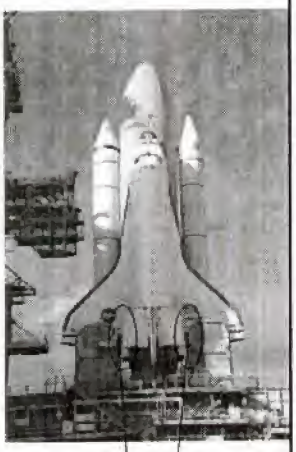
Ground Capabilities & Constraints



4

Ground Capabilities & Constraints

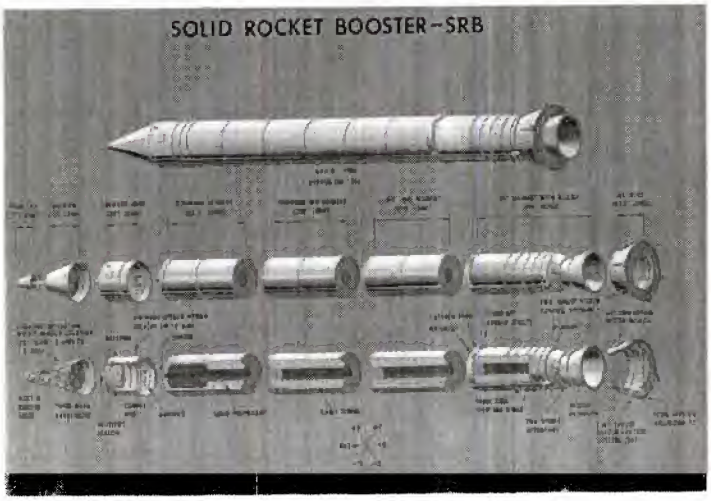
1. **T-0 Umbilical**
   - Allows vehicle instruments to be monitored and recorded prior to launch.
   - Retracts during launch.
2. **Launch Complex Instrumentation**
   - Instruments needed for assessment of Launch Commit Criteria (LCC).
   - Salt-air and launch environments are issues.
3. **Drag-On instrumentation**
   - Instrumentation can be added as needed to the vehicle for non-flight use.
   - The current Roll-out Fatigue Testing is a primary example.



T-0 Umbilicals

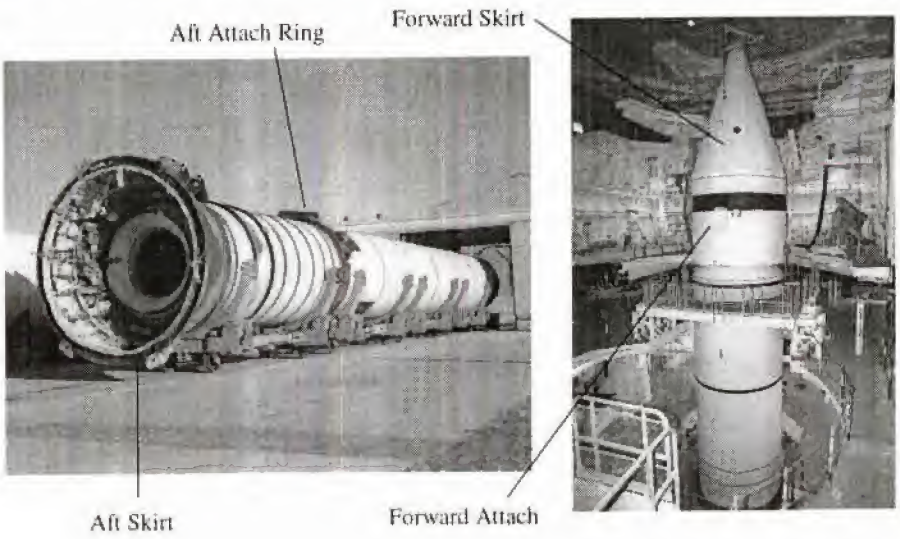
5

SRB Capabilities & Constraints



6

SRB Capabilities & Constraints



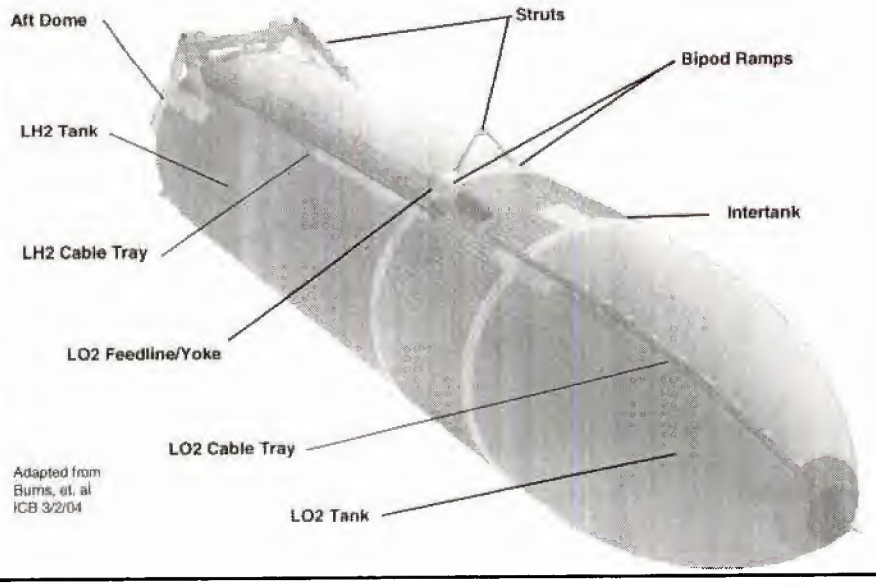
7

SRB Capabilities & Constraints

1. **On-board recording is available (1st Stage Only).**
   - Chamber pressures and accelerations are recorded.
   - Recording capability may be expanded.
2. **Systems must survive difficult environments.**
   - Launch – acoustics, heat, overpressure.
   - Recovery – water impact and immersion.
3. **Must be electrically benign.**
   - Solid Rocket Boosters are always loaded.
   - Hydrazine powered APUs and Booster Separation Motors are also on-board.

8

ET Capabilities & Constraints

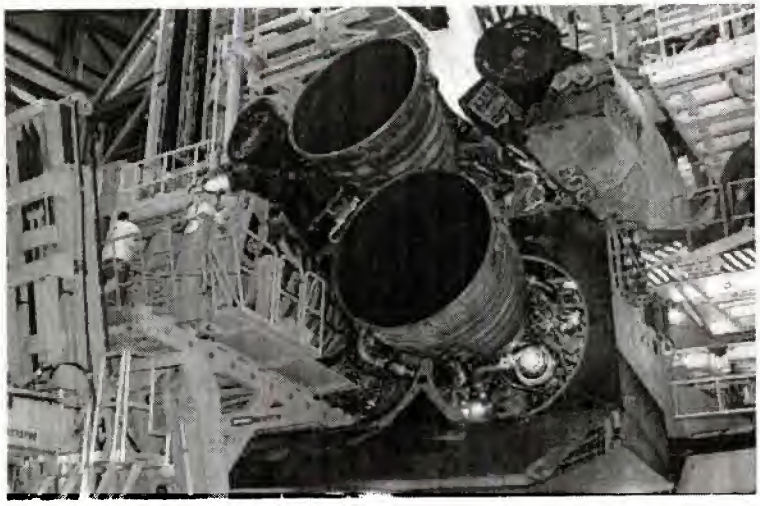


ET Capabilities & Constraints

1. **The system is not recovered.**
   - Historically the Orbiter has recorded the data.
   - Telemetry is typically used now for cameras.
2. **The environment is dangerous.**
   - Cryogenic temperatures and aerodynamic heating.
   - Hydrogen gas is potentially present.
3. **Potential debris generation must be reduced.**
   - Any external instrumentation must not become a debris source.
   - The local foam insulation must not be weakened and released.

10

MPS Capabilities & Constraints



MPS Capabilities & Constraints

1. The engines are already instrumented.

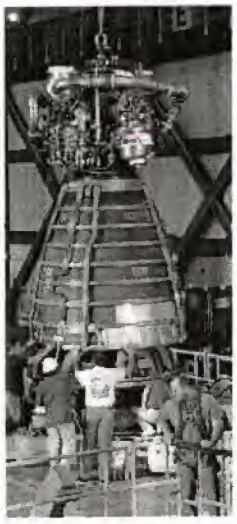
- The Orbiter records and transmits the data.
- Most sensors are for engine performance.

2. The environment is dangerous.

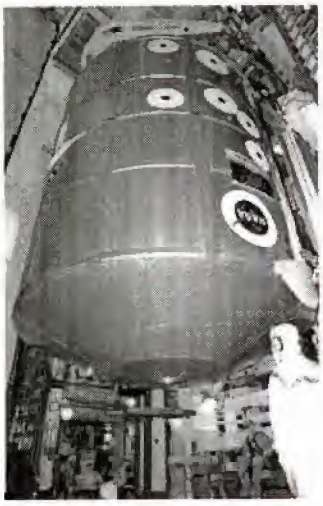
- Cryogenic temperatures and combustion-induced heating
- Hydrogen and Oxygen gas are potentially present.

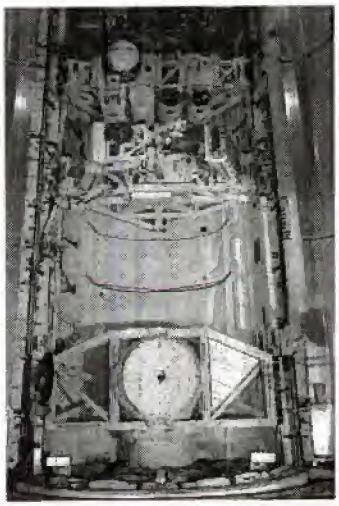
3. The environment is highly dynamic.

- Acoustics, dynamics, and thermal shocks are all issues.
- The resulting environment is highly complex.



Cargo Integration Capabilities & Constraints



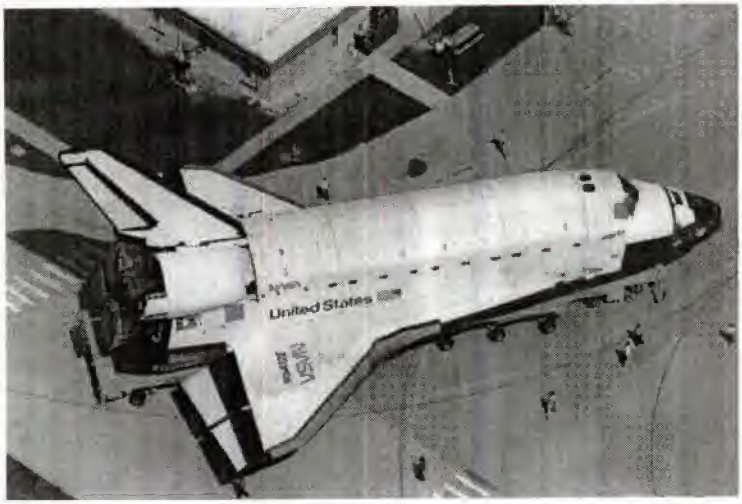


Cargo Integration Capabilities & Constraints

1. **The system is always changing.**
   - Payloads change from flight-to-flight and can interact significantly.
   - The dynamic environment and response are therefore variable.
2. **There are limited electrical feeds to cross the Orbiter interface.**
   - The MADS system instruments the longeron on OV-103 & OV-102.
   - SAAMD, WB-SAAMD, Micro-TAU, and Wide-Band Micro-TAU are stand-alone units.
3. **Time-synchronization is needed.**
   - Multiple systems make this nearly-impossible today.
   - Mix of permanent and stand-alone systems.

Stand-Alone Acceleration Monitoring Device (SAAMD)

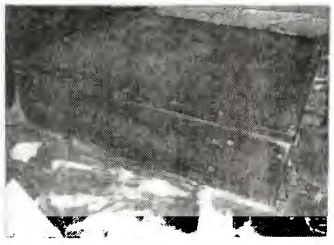
Orbiter Capabilities & Constraints



15

Orbiter Capabilities & Constraints

1. **The Orbiters are self-contained systems.**
   - Each vehicle has power and telemetry.
   - Each vehicle has a (Modular Auxiliary Data System) MADS recorder.
2. **Sensors are difficult to install.**
   - Tile replacement and substructure access (nose, tail) is an issue.
   - Significant engineering support for installation, wiring, certification.
3. **MADS System is difficult to change.**
   - Specific sensors types/sampling rates.
   - Analog recording - no on-orbit play-back.



16

Shuttle System Overview - Orbiters

Table of MADS Channels by Orbiter

Sensor Type	Columbia OV-102	Discovery OV-103	Atlantis OV-104	Endeavor OV-105
Pressure	249	64	-	1
Strain	373	27	14	17
Temperature	96	5	22	9
Accel/Vib	22	54	3	18
Other	11	10	-	40
Total (Excluding Other)	740	150	39	45

17

Shuttle System Overview – ET,SRB's, MLP

Instrumentation by Element

- **ET** – None
- **SRB's**
  - Low Sample Rate Chamber Pressure
  - Accelerometers
- **MLP** – 5 Microphones

18

Shuttle Instrumentation Issue: Number of Requested Sensors

- Original VHMS Request from Loads – 881 Channels
- Original RTF Request from Loads - 383 Channels
- Removing Pre-Approved Channels – 230 Channels
- Program Agreed to Consider – 206
- Maximum That Elements Can Support on STS-114 – 44
- Maximum That Elements Can Support on any of the first six missions – 178
- Possible Solution – Cheap MEMS Sensors

19

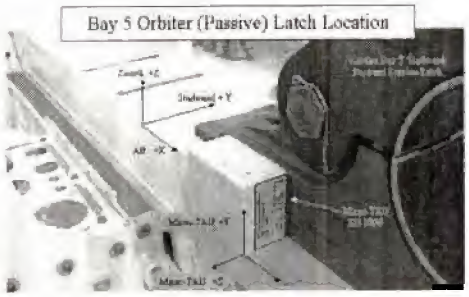
Instrumentation Issue: Manned Spaceflight Certification

- Problem – Certification is costly
  - Environmental testing is required
  - Paper trail for each sensor
  - Materials must be approved
  - Batteries must be approved
  - Acceptance testing is required
  - All other safety issues must be addressed
- Possible Solution – Lower the size, weight, and power

20

Instrumentation Issue: Integration Engineering

- **Problem – Integrating a sensor on the Shuttle is costly**
  - Attach hardware must be designed and built
  - Wiring runs must be designed and built
  - Drawings must be produced
  - Installation must be planned in the flow
  - Maintenance must be planned and performed



- **Possible Solution – Small wireless systems**
  - Already flying wireless units on the Shuttle
  - Already flying units small enough for adhesive mounting

21

Instrumentation Issue: Large Dynamic Range Needed

- **Problem – The Shuttle sees a wide range of excitation**
  - Launch, Hi-Q, and Staging have extremely high loading
  - Input fades to a lower value before ET separation
  - Some very telling events produce minimal change in a signal
- **Possible Solution – MEMS-based sensors**
  - MEMS-based sensors can have an extremely high dynamic range
  - Ultra-small size keeps the sensor resonances very high

22

Instrumentation Issue: Time Synchronization Needed

- **Problem – Multiple sensor systems cannot be synchronized**
  - Looking for validation of system level models
  - Looking for system-level response
  - Looking for system-level anomalies
  - Looking for system-level forcing functions
  - System-level means that time synchronization is important
- **Possible Solution – Is there one?**
  - There is no near-term solution
  - An advanced Vehicle Health Monitoring System might be capable

Instrumentation Issue: Obtaining SRB Chamber Pressures

- **Problem – Internal chamber pressures are difficult to obtain**
  - Need chamber pressures at more than one location
  - The SRB's dominate everything during first stage flight
  - Environment is extremely harsh
  - No desire to create additional holes in case
- **Is there a solution?**

Instrumentation Issue: Recording ET Data

Atlas V

- **Problem – The ET has no data recorder**
  - The ET is expendable
  - The ET has no power source
  - The ET has a couple of antenna, but they are dedicated to video
- **Near Term Solution – Record the data on the SRB's**
  - Additional recorders can be flown on the SRB's
  - The SRB's are recovered
  - Limited data and recording time
- **Long Term Solution – Provide the ET a stand-alone system**
  - A data system from an Atlas rocket can be used
  - Must be man-rated and certified
  - Will take up to two years to certify and implement

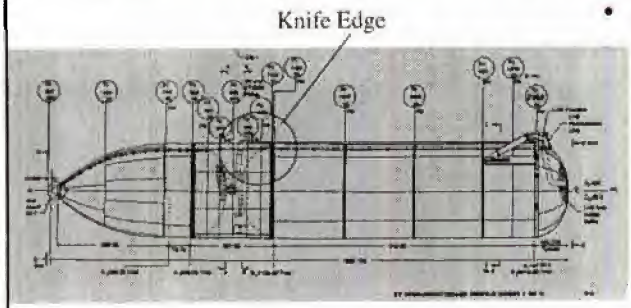
Instrumentation Issue: Recording ET Data

Range Safety Cable
Between SRB & ET

EDAS Recorders in the SRB

Instrumentation Issue: Internal ET Sensors Needed in Small Area

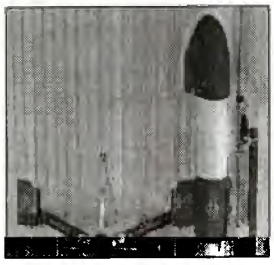
- **Problem – The LH2 Tank/Intertank Ring Is a Tight Fit**
  - The forward Orbiter attach is on the Lowest Intertank Ring
  - This ring comes to a knife edge at the Liquid Hydrogen dome
  - An internal stiffener further crowds the area
  - Cryogenic temperatures exist
  - Acceleration, vibration
  - Sensors can be mounted before assembly if they are small enough



- **Possible Solution: MEMS-size sensors**
  - Allows internal monitoring
  - Avoids skin panel effects

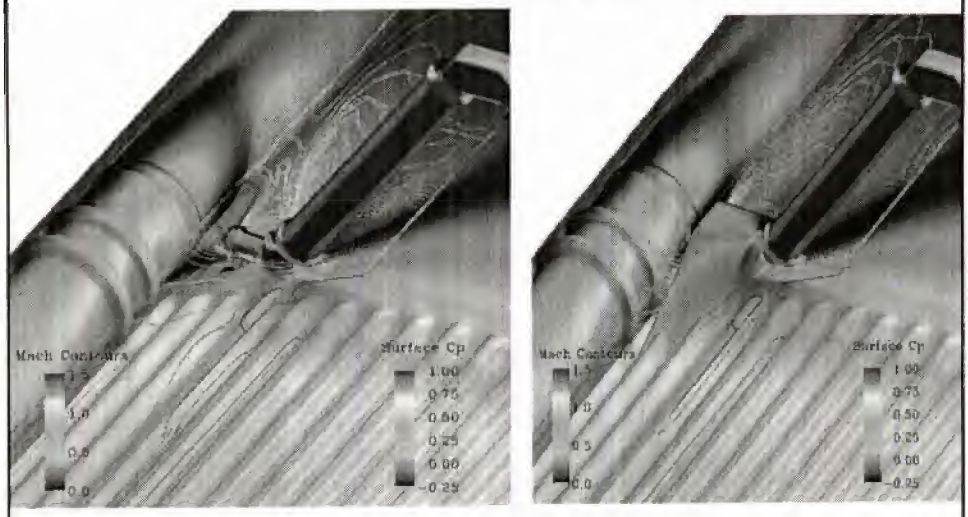
Instrumentation Issue: External ET Sensors can be a Debris Hazard

- **Problem – Several ET Sensors must be mounted externally**
  - Up to six ET's are covered in TPS* (Foam)
  - External sensors will require removing and replacing large sections
  - External sensors will also be a debris hazard
  - Later ET's have bare skin
  - Bare-Skin applications will see cryogenic temperatures
  - The ET experiences significant cryo-shrinkage
  - Pressure, microphone, vibration, temperature, strain
- **Possible Solution – MEMS-size sensors**
  - Keep the size below the debris danger level
  - Smart Dust Concepts



* TPS – Thermal Protection System

Instrumentation Issue: ET LOX Feedline Bracket



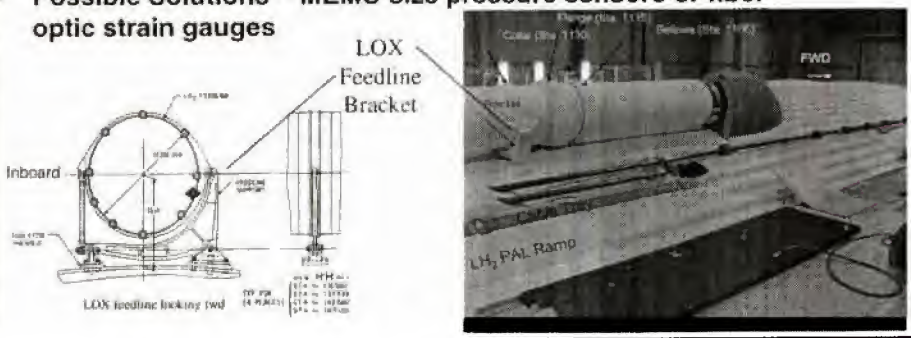
29

Instrumentation Issue: ET LOX Feedline Bracket

- **Problem – The ET LOX Feedline Bracket is a challenge**
  - Aero Loads on the ET LOX Feedline will increase
  - Validate CFD* with pressure or strain
  - Mounting strain gauges on the bracket is difficult
  - Pressure sensors require degrading TPS integrity

*CFD: Computational Fluid Dynamics

- **Possible Solutions – MEMS-size pressure sensors or fiber-optic strain gauges**



30

Instrumentation Issue: Orbiter Wiring

- **Problem – Wiring the Orbiter is difficult**
  - OV-103 has some wiring in place
  - OV-104 & OV-105 have little wiring in place
- **Possible Solution – Wireless sensor systems**

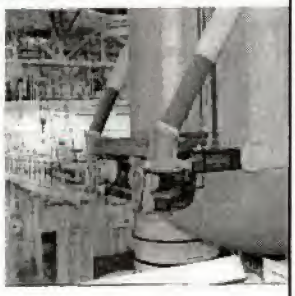
Wiring in OV-102 Wing Box

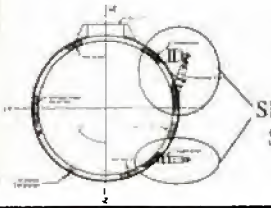
31

Instrumentation Issue: Strut Strain Gauge Calibration

- **Problem – Strain gauges on attach struts require calibration**
  - SRB-ET struts can be performed by the vendor
  - SRB-ET struts do not have major TPS concerns
  - Orbiter-ET struts have to be performed on the vehicle
  - The calibration frame may be unavailable
  - TPS-covered struts are an issue
- **Possible Solution – Fiber Optic Sensor systems**
  - May not help calibration issue
  - May help installation and recording issue

Aft ET/Orb Struts





SRB/ET Struts

Fwd. ET/Orb Bipod Struts

32

Instrumentation Issue: Orbiter TPS Change-Out

- **Problem – Some Sensors require special Orbiter tiles**
  - Pressure, temperature, and microphones on external surfaces
  - Significant engineering and installation
- **Possible Solution – Small sacrificial sensors, smart dust**

33

Issues Summary

- **Issues:**
  - Number of Sensors
  - Certification
  - Integration Engineering
  - Dynamic Range
  - Time Synchronization
  - SRB Chamber Pressures
  - No ET Recorder
  - Internal ET Sensors in a Small Area
  - External ET Debris Hazard
  - ET LOX Feedline Bracket
  - Orbiter Wiring
  - Orbiter TPS Change-Out
  - Strut Strain Gauge Calibration

34

Conclusions

1. Instrumenting the Shuttle system will be a challenge.
2. New Technologies Should be considered where appropriate.
3. Wireless Sensors, Smart Dust, Fiber-Optic Strain Gauges, MEMS-based sensors are possible technologies.

35